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Coleshill Junction river modelling report (WR-004-012)

Water resources

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Appendix WR-004-012

Environmental topic:	Water resources and flood risk assessment	WR
Appendix name:	River Modelling	004
Community forum area	Coleshill Junction	019

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1 Overarching modelling approach

1.1 Introduction

1.1.1 This section of the Proposed Scheme crosses numerous watercourses with the potential for affecting flood risk. Hydraulic modelling has been carried out to assess the current (baseline) river flood risks at each of these watercourse crossings and the potential impacts of the proposed culvert and viaduct structures. Therefore, the primary objective of this assessment was to assess the impact of the Proposed Scheme on river flood risk.

1.1.2 The outcome of this assessment will aid the design to determine the type and dimension of structures required to convey the watercourse flows; and mitigation measures for any remaining residual flood risk.

1.1.3 A hydraulic modelling assessment of flood risk was undertaken for watercourses affected by this section of the Proposed Scheme. These watercourses were grouped into seven CFA in the Country North Section. Existing hydraulic models of the watercourses have been utilised where available; and new river hydraulic models were built for the other watercourses. This report describes the hydraulic modelling processes and outcomes of this assessment.

1.1.4 The main conclusions from this modelling report form the basis of the river flood risk in the Flood Risk Assessment for Community Forum Area 19 – Coleshill Junction (WR-003-019). These conclusions are also reported within the Water Resources and Flood Risk Assessment section of Volume 2 of the Environmental Statement (ES).

1.2 Hydrology

1.2.1 Watercourses with existing hydraulic models adopted standard Flood Estimation Handbook (FEH) techniques for hydrological assessment. The hydrology of these models was reviewed for suitability for use in this study.

1.2.2 For the watercourses with no existing hydraulic models, hydrological assessments were undertaken in this study to determine the design flows.

1.2.3 The hydrological catchments of the watercourses to each of the route crossings have been determined from the FEH CD-ROM[1] for watercourses represented in this data set. For the purposes of this assessment it was assumed that catchment boundaries as represented in the FEH CD-ROM were correct, therefore a detailed assessment of catchment boundaries has not been completed. The catchment descriptors have also been taken from the FEH CD-ROM and updated for urban expansion to 2012, using Equation 6.8 in Volume 5 of the FEH[2]. This is a standard industry technique.

1.2.4 River flows at watercourse crossing locations were determined using the Revitalised Flood Hydrograph (ReFH) method[3] in the first instance. In line with the current Environment Agency flood estimation guidance, the ReFH method is deemed acceptable for the majority of catchments along the route and is the most time

[1] Centre for Ecology and Hydrology (2009) *FEH CD-ROM Version 3*, ©NERC (CEH).
[2] Centre for Ecology & Hydrology (CEH) (1999). *Flood Estimation Handbook – Volume 5: Catchment Descriptors*.
[3] Centre for Ecology & Hydrology (CEH) (2007). *The revitalised FSR/FEH rainfall-runoff method: Supplementary Report No. 1.*

efficient method for determining flows for studies where numerous flows are required.

1.2.5 The ReFH method is not considered acceptable for all catchments, in this case those classed as highly permeable. Based on the FEH CD-ROM catchment descriptors, a number of the catchments are classed as highly permeable and hence in line with current Environment Agency guidelines[4], an alternative method was required. Therefore at these locations, the FEH Statistical method, with a permeable adjustment was utilised, as recommended in the guidelines.

1.2.6 Not all watercourses that will be crossed by the route were represented in the FEH CD-ROM; therefore, the catchment boundaries could not be determined using the FEH CD-ROM. In these instances, catchment boundaries have been determined through the use of topographic data from Light Detection and Ranging (LiDAR) data and Ordnance Survey (OS) mapping at a 1:10,000 scale. At locations of uncertainty, a slightly larger catchment has been assumed as a conservative approach. Flows for these catchments were determined through a conservative area scaling method. Based on the flows estimated for FEH CD-ROM represented catchments, a maximum flow rate of 1.4 and 2.6m^3/s per km^2 was calculated for the 1 in 100 (1%) annual probability and 1 in 1000 (0.1%) annual probability events respectively. These flow rates, along with 10% error allowance (to prevent an underestimation of flow), were used as scaling factors.

1.2.7 The estimated peak flows were used as either a constant inflow boundary or as a full hydrograph. The peak flows estimated using this method were for the 1 in 20 (5%) annual probability, 1 in 100 (1%) annual probability and 1 in 1000 (0.1%) annual probability events. Flow during the 1 in 100 (1%) annual probability event with an allowance for climate change was estimated by factoring the 1 in 100 (1%) annual probability flow by 20% (refer to Section 3 of the Flood Risk Assessment WR-003-019).

1.3 Hydraulics

General approach

1.3.1 The hydraulic modelling approach depended on the characteristics of the particular watercourse and floodplain hydraulics. The approach of either steady or unsteady modelling was based on whether there were rapid increases or decreases in flows, flood storage areas or structure impacts on channel/floodplain flows. The modelling approach also varied based on requirements of assessing the flow routes either in one dimension or two dimensions.

1.3.2 The modelling approach adopted in this study was as follows:

- if the modelling was utilised for sizing the culvert crossings on watercourses with no significant floodplain attenuation or structure impacts, steady state one dimensional modelling was adopted;
- if there was significant floodplain attenuation and/or structure impacts on channel/floodplain flows, one dimensional hydrodynamic modelling was adopted; and

[4] Environment Agency (2012). Flood estimation guidelines (197_08).

- if there was significant floodplain attenuation and/or structure impacts on channel/floodplain flows, and a requirement for accurately defining the flood extents, two dimensional or a one dimensional – two dimensional combination modelling was adopted.

1.3.3 Existing models were first reviewed to assess their suitability for use. If more recent data such as topography was available the models were updated accordingly. If the level of detail within the model, such as the floodplain, was not appropriate, the model was upgraded accordingly.

1.3.4 The hydraulic modelling approach was based on the Environment Agency guidelines[5].

1.3.5 Two industry standard modelling packages have been utilised as part of this assessment: ISIS (version 3.6) and TUFLOW (version 2012).

Hierarchical approach

1.3.6 Any existing Environment Agency models for the watercourses were used to assess the current and future flood risk impacts of the route crossing the watercourses.

1.3.7 For watercourses without existing hydraulic models, the modelling process was carried out in a phased manner to assess the baseline flood risk and impacts of the Proposed Scheme. In the first phase, the watercourses with culverted crossings were modelled as simple unsteady one dimensional hydraulic models, to assess the adequacy of culverts in conveying flood flows. In the second phase, watercourses for both culverted and viaduct crossings were modelled as two dimensional hydrodynamic models to define the flood extents and assess the impacts of the various structures on flood risk. The two dimensional model outputs were then used to inform the design team of flood risk.

1.3.8 All the models were run for the 1 in 100 (1%) annual probability with an allowance for climate change and 1 in 1000 (0.1%) annual probability events. Some of the models were run for the 1 in 20 (5%) annual probability where the potential impacts on flood risk could affect vulnerable receptors.

1.3.9 The 1 in 100 (1%) annual probability with an allowance for climate change peak water levels for the baseline and Proposed Scheme were compared upstream and downstream of the crossing to assess the impact on flood risk. The scheme impact on flood risk and the width of the 1 in 100 (1%) annual probability with an allowance for climate change flood extents, defined the type of structure to be used at the crossings i.e. culvert or viaduct and the dimensions of culverts/viaducts. The structure type was selected based on its adequacy in conveying flood flows without significantly affecting flood risk.

1.3.10 The peak water levels for the 1 in 1000 (0.1%) annual probability event confirmed whether the vertical alignment met the design criteria (refer to Section 3 of the Flood Risk Assessment WR-003-019).

[5] Environment Agency (August 2009), '*Requirements for completing computer river modelling for flood risk assessments – Guidance for developers' Version 3.0*.

Input data

1.3.11 The topographic data used was LiDAR data that was flown in 2012, covering the extent of the Proposed Scheme, providing data as detailed as up to 0.2m horizontal resolution. This data was used to create digital terrain models (DTM) for use within the hydraulic models. In most cases, the DTM has been resized to a 1m resolution for greater suitability in the two dimensional models. For watercourses without existing hydraulic models, there were no topographic surveys available and hence river sections and floodplain topography were derived from these DTM.

1.3.12 For existing models, the floodplain topography was updated with this new DTM. The channel topography in these models was taken from topographic surveys undertaken previously.

1.3.13 Inflows to the watercourses were taken from the hydrological assessments as discussed in Section 0 of this report.

1.3.14 The data for the Proposed Scheme model scenario was taken from the scheme drawings.

One dimension modelling

1.3.15 In the first phase, one dimensional ISIS models were constructed representing a 200m to 300m reach of the watercourse. The purpose of these models was to assess the adequacy of culverted crossings in conveying flows. These models used the LiDAR data to define extended cross sections which included the channel and floodplain topography. The roughness of the channels and floodplains is defined by the Manning’s roughness parameter. The Manning's values of channels and floodplains were based on the particular land use type as observed from aerial photographs. Steady state flows were applied as upstream inflow boundaries and a normal depth boundary was applied at the downstream extent. The normal depth boundary was based on the bed slope of the topography at that location and is considered suitable for the purpose of the modelling.

1.3.16 The Proposed Scheme model included rectangular conduit units to represent the structures at the crossings. There were two types of culverts adopted: minimum culvert size of 2m by 1.5m and a maximum culvert size of 4m by 2m. The dimensions adopted here represent the flow area of the culvert rather than the full dimensions of the culvert that would need to be larger to accommodate depressed inverts and mammal ledges as appropriate. The lengths of the culvert were based on the width of the route crossings as defined in the scheme design.

Two dimension modelling

1.3.17 In the second phase, unsteady state two dimensional TUFLOW models were built to accurately define the flood extents and floodplain attenuation. The two dimensional models were built on a 5m cell resolution with LiDAR data used to create the DTM, which defined the floodplain and channel topography.

1.3.18 It should be noted that components within a two dimensional TUFLOW model such as SXZ, HX, Z-polygon, Z-Shape polygons, etc., are based on naming conventions as defined in the TUFLOW manual[6].

1.3.19 The Manning's roughness values of the channels and floodplains were based on the particular land use type as observed from aerial photographs.

1.3.20 The inflow to each watercourse was applied upstream using a TUFLOW boundary condition polyline layer, linking it to a flow time series within a boundary condition database. The flow type is either constant flow or hydrograph flow, depending on the attenuation within the floodplain. A flow-head (HQ) polyline layer was used for the downstream boundary, based on the slope of the floodplain at that location; which was considered suitable for the scale and level of detail of the modelling. The models have been run at a two second timestep for varying durations.

1.3.21 The Proposed Scheme model was built by adding either culvert or viaduct structures to the baseline model at the watercourse crossings.

1.3.22 Viaduct structures have been modelled by adding the Proposed Scheme embankments as Z-polygon or Z-Shape polygon layers with an opening at the viaduct crossing. The Z-polygon or Z-Shape polygon layers are Geographic Information System (GIS) polygons with elevations. Where piers were modelled, they were represented as Flow Constriction (FC) shape layers. The soffit levels were not added into the model. This was because the 1 in 1000 (0.1%) annual probability modelled peak flood levels, along with sufficient clearance, will form the basis of designing the soffit heights (refer to Section 3 of the Flood Risk Assessment WR-003-019).

1.3.23 Culvert structures have been modelled by adding a one dimensional network layer representing the extent of the culvert, the length of which was determined by the width of the route at the crossing point (including embankment earthworks and any landscaping). Inverts were defined at the inflow and outflow points of the culvert extracted from the LiDAR DTM for the area. This one dimensional network layer was connected to the two dimension domain with an SXZ point link; a GIS point used in the modelling software for one dimension-two dimension linking. An embankment was modelled across the route as a Z-polygon layer, covering the extent of the upstream floodplain at the route crossing so that all flow was routed through the culvert.

one dimension-two dimension linked modelling

1.3.24 In certain cases where existing one dimensional models were not representing complex channel-floodplain interactions accurately, dynamically linked one dimensional-two dimensional models were constructed. The channel component was represented in one dimension and the floodplain component in two dimensions. These models were built using ISIS-TUFLOW.

1.3.25 The flows between the one dimensional and two dimensional model components were controlled via a GIS polyline layer (HX layer), the spill levels of which are defined by the channel bank levels or DTM levels.

[6] BMT WBM, (2010). TUFLOW User Manual.

1.3.26 In the Proposed Scheme scenarios, the viaduct structures are represented as discussed earlier in the two dimensional modelling section (Section 1.3.22 of this report).

Sensitivity assessments

1.3.27 Sensitivity assessments have been undertaken on various parameters of the models to reflect the uncertainties and impacts on modelled flood levels. Assessments have been carried out on inflows and culvert blockages. In the case of viaduct crossings, sensitivity was undertaken on inflows.

1.3.28 Sensitivity assessment on inflows was carried out by varying the 1 in 100 (1%) annual probability with an allowance for climate change and the 1 in 1000 (0.1%) annual probability flows by 20%. This was undertaken for the baseline and post scheme scenarios, unless stated otherwise.

1.3.29 Sensitivity assessment has also been carried out on Proposed Scheme scenarios with culvert structures by adding 10% blockage. Resulting models have been run for the 1 in 100 (1%) annual probability with an allowance for climate change and the 1 in 1000 (0.1%) annual probability events.

1.4 Assumptions and limitations

Hydrology

1.4.1 The catchment boundaries and catchment descriptors as taken from the FEH CD-ROM are correct and accurately represent the catchments in reality.

1.4.2 For catchments not classed as highly permeable, the ReFH method results in the most accurate estimation of flow at the location of the crossings in comparison to other methods.

1.4.3 The FEH Statistical method with permeable adjustment results in the most accurate estimation of flow at catchments classed as highly permeable.

1.4.4 The flow scaling method, which is based on area, results in conservative flow estimates for catchments which are not represented in the FEH CD-ROM (refer to Section 0 of this report for detail).

1.4.5 There are no external influences on flow at the location of the crossing, such as significant abstractions or discharges.

1.4.6 A 20% allowance for climate change on peak flow rates has been used for the assessment of river flood risk.

Hydraulic modelling

1.4.7 Only river flood risk was considered during the hydraulic modelling in this assessment.

1.4.8 For watercourses without existing hydraulic models, the watercourse geometry was extracted from the LiDAR DTM with the channel width defined by the 5m cell resolution of the two dimensional model. Therefore, the watercourse geometry is not well defined, the consequence of which is an underestimate of the channel conveyance and hence, an overestimation of the floodplain inundation.

1.4.9 There will be certain watercourses with road crossing structures upstream or downstream of a route crossing, causing a significant impact on hydraulics. OS Mapping and aerial photography were used to assess the location of the structures. The inverts of any culvert structure were assumed to be the channel bed levels from the LiDAR DTM; and structure widths as the width of the channel.

1.4.10 In the Proposed Scheme for models involving viaducts, the structure was represented by the piers and embankments. The scheme drawings were used to obtain the footprint of the piers and the dimensions incorporated into the model. The soffits of the viaducts were not modelled as the design approach for the structures is to include a suitable clearance between peak flood level and the structure soffit.

2 Modelling at watercourse crossings

2.1 Overview

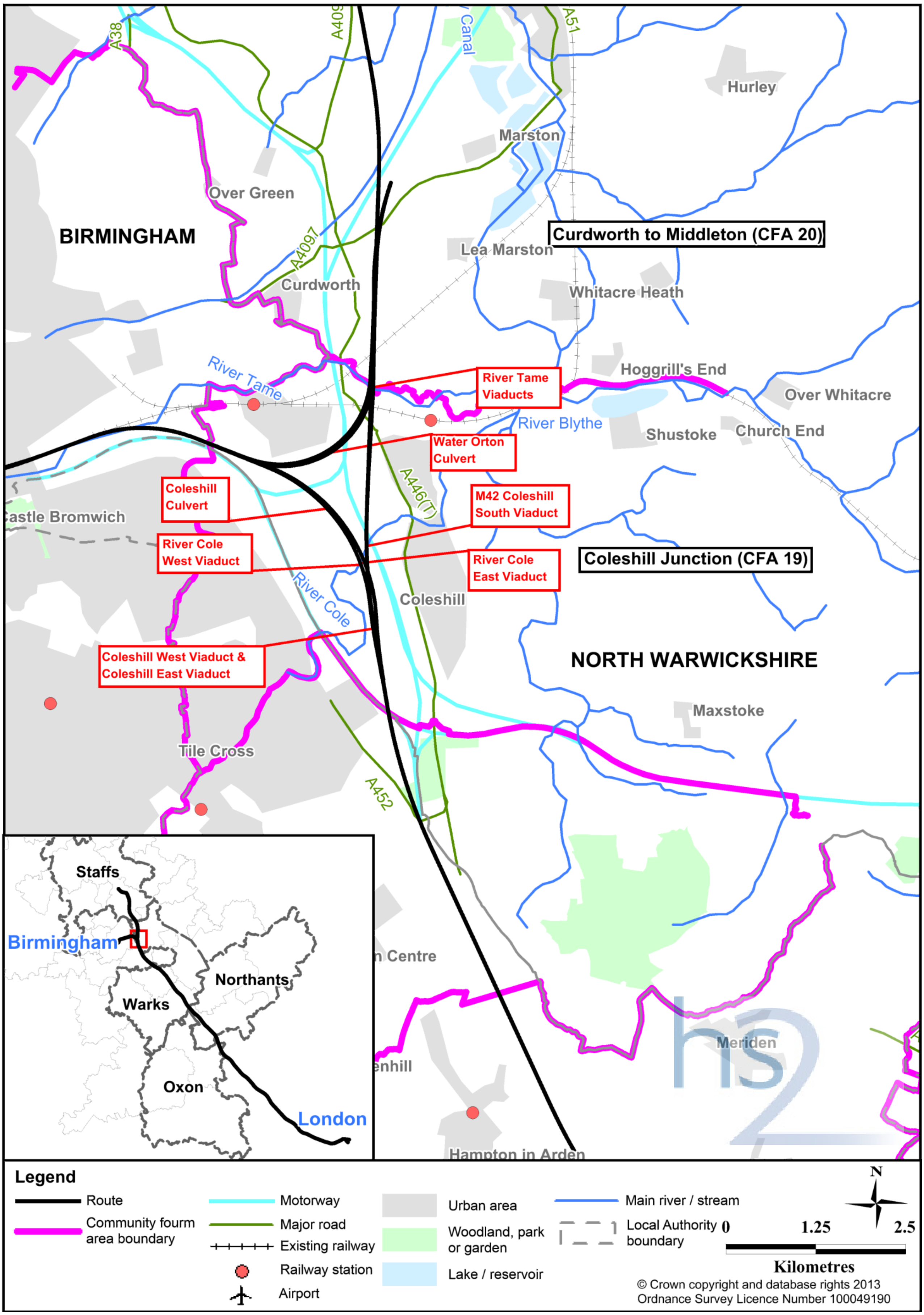
2.1.1 River modelling undertaken at the various watercourse crossings for CFA19 are summarised in Table 1, along with the modelling methodologies adopted. The River Tame viaducts mentioned in Table 1 comprises of the River Tame west viaduct, River Tame east viaduct and Water Orton No.2 viaduct. Figure 1 identifies the location of each of these structures.

Table 1: River models at watercourse crossings

Crossing name	Watercourse identifier and map reference	Watercourse	Hydrology	Hydraulic modelling
Coleshill West viaduct and Coleshill East viaduct	SWC-CFA19-003 Volume 5: Map Book – Water Resources, Map WR-05-054, C6	Ordinary watercourse (River Cole tributary)	FEH Statistical	two dimensional hydrodynamic
Coleshill West viaduct and Coleshill East viaduct	SWC-CFA19-004 Volume 5: Map Book – Water Resources, Map WR-05-055, I5	Ordinary watercourse (River Cole tributary)		
River Cole West viaduct	SWC-CFA19-005 Volume 5: Map Book – Water Resources, Map WR-05-055, G6	Main river (River Cole)		
River Cole East viaduct	SWC-CFA19-005 Volume 5: Map Book – Water Resources, Map WR-05-055, G6	Main river (River Cole)		
M42 Coleshill South viaduct	SWC-CFA19-006 Volume 5: Map Book – Water Resources, Map WR-05-055, G5	Main river (River Cole)		
Coleshill culvert	SWC-CFA19-010 Volume 5: Map Book – Water Resources, Map WR-05-055, E8	Ordinary watercourse (River Cole tributary)	ReFH	one dimensional steady state
Water Orton culvert	SWC-CFA19-019 Volume 5: Map Book – Water Resources, Map WR-05-055, C7	Ordinary watercourse (River Tame tributary)	ReFH	one dimensional steady state
River Tame viaducts	SWC-CFA19-013 Volume 5: Map Book – Water Resources, Map WR-05-055, A5	Main River (River Tame)	FEH Statistical	one dimensional hydrodynamic

2.1.2 A summary of the modelling for the two culvert structures (Coleshill culvert and Water Orton culvert) is described in Section 2.1.3 of this report. The modelling is described in detail for each of the viaduct structures in the subsequent sections of this report.

Figure 1: Location plan



2.1.3 The hydrology for the River Cole and its tributaries has been taken from the Environment Agency Flood Risk Mapping Study[7]. Details of the hydrology will be discussed in the next section.

2.1.4 For the River Tame, the hydrology and hydraulic model was taken from the Environment Agency Flood Risk Mapping Study[8]. The hydraulic model was amended near the crossing for the current scenario and scheme scenario which will be discussed in the next section.

2.1.5 The details of the specific modelling methodologies, hydraulic constraints and any assumptions of each of the watercourse crossings are discussed in the following sections.

2.2 Culverts

2.2.1 The one dimensional ISIS hydraulic models built for the baseline and post scheme scenarios used the general methodologies for one dimensional modelling as discussed in Section 1.3.7 of this report.

2.2.2 The structures adopted at Coleshill culvert (SWC-CFA19-010) and Water Orton culvert (SWC-CFA19-019) along with their impacts on peak flood levels is summarised in Table 2. The dimensions of the culvert flow area of Width (W), Height (H) and Length (L) in metres is also provided in this table.

2.2.3 The methodology applied for the hydrological assessment is provided in the FEH proforma in Section 0 of this report.

Table 2: Modelled peak levels for culvert crossings

Watercourse identifier	Culvert dimensions (WxHxL)	Flood event	Peak flood level		Change in flood level	Length of impact upstream reach[9]
			Baseline	Scheme		
SWC-CFA19-010	4m x 2m x 156mm	1 in 100 (1%) climate change	84.278mAOD	84.278mAOD	0mm	0m
		1 in 1000 (0.1%)	84.382mAOD	84.382mAOD	0mm	
SWC-CFA19-019	4m x 2m x 100m	1 in 100 (1%) climate change	80.665mAOD	80.665mAOD	0mm	0m
		1 in 1000 (0.1%)	80.714mAOD	80.714mAOD	0mm	

2.2.4 For Coleshill culvert, peak levels there were no increase in peak levels upstream of the crossing for the 1 in 100 (1%) annual probability with an allowance for climate change event. Therefore, this structure will not increase flood risk.

2.2.5 For Water Orton culvert, peak levels there were no increase in peak levels upstream of the crossing for the 1 in 100 (1%) annual probability with an allowance for climate change event. Therefore, this structure will not increase flood risk.

[7] Environment Agency (2007) *River Cole Flood Risk Mapping Study*. Completed by JBA on behalf of the Environment Agency.
[8] Environment Agency (2009) *River Tame Hazard Mapping*. Completed by Halcrow on behalf of the Environment Agency.
[9] Length of reach upstream of the scheme along which flood levels during the 1 in 100 (1%) annual probability with an allowance for climate change are greater than 10mm.

2.3 Coleshill West viaduct, Coleshill East viaduct, River Cole West viaduct, River Cole East viaduct and M42 Coleshill South viaduct

2.3.1 The reach of the River Cole and its tributaries between the M6 and M42 bridges will be crossed by several viaducts as shown in Figure 2. In Figure 3, the schematics of the crossings and flood extents of the Proposed Scheme are provided. The general flow direction of the River Cole in this reach is from south-west to north-east. The tributaries to the River Cole are referred to by their ISIS boundary node names as in the original Environment Agency model.

2.3.2 The first of the structures are the Coleshill West and East viaducts which will cross ordinary watercourses SWC-CFA19-010 (ISIS model node 'Trib_02') and SWC-CFA19-019 (ISIS model node 'Trib_03'). The River Cole will then be realigned from upstream of Manor Road bridge to the M42 bridge. Within this diverted reach, the River Cole will be crossed by the River Cole West and East viaducts and the M42 Coleshill South viaduct. In addition to the viaducts, the original Manor Road would be realigned for access purposes and the elevation will be raised above the peak levels for 1 in 100 (1%) annual probability with an allowance for climate change event.

Figure 2: Crossing location and baseline flood extents

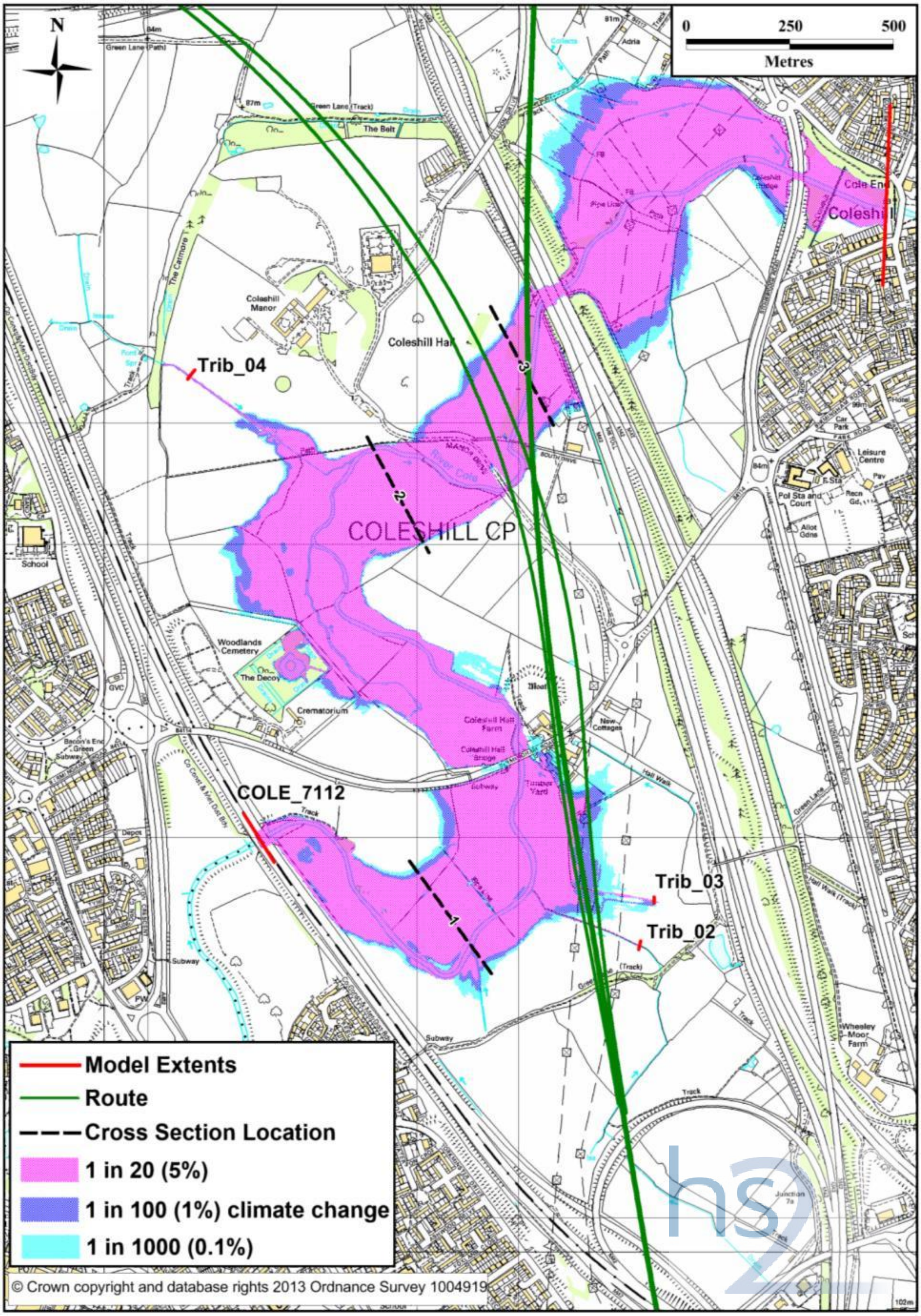
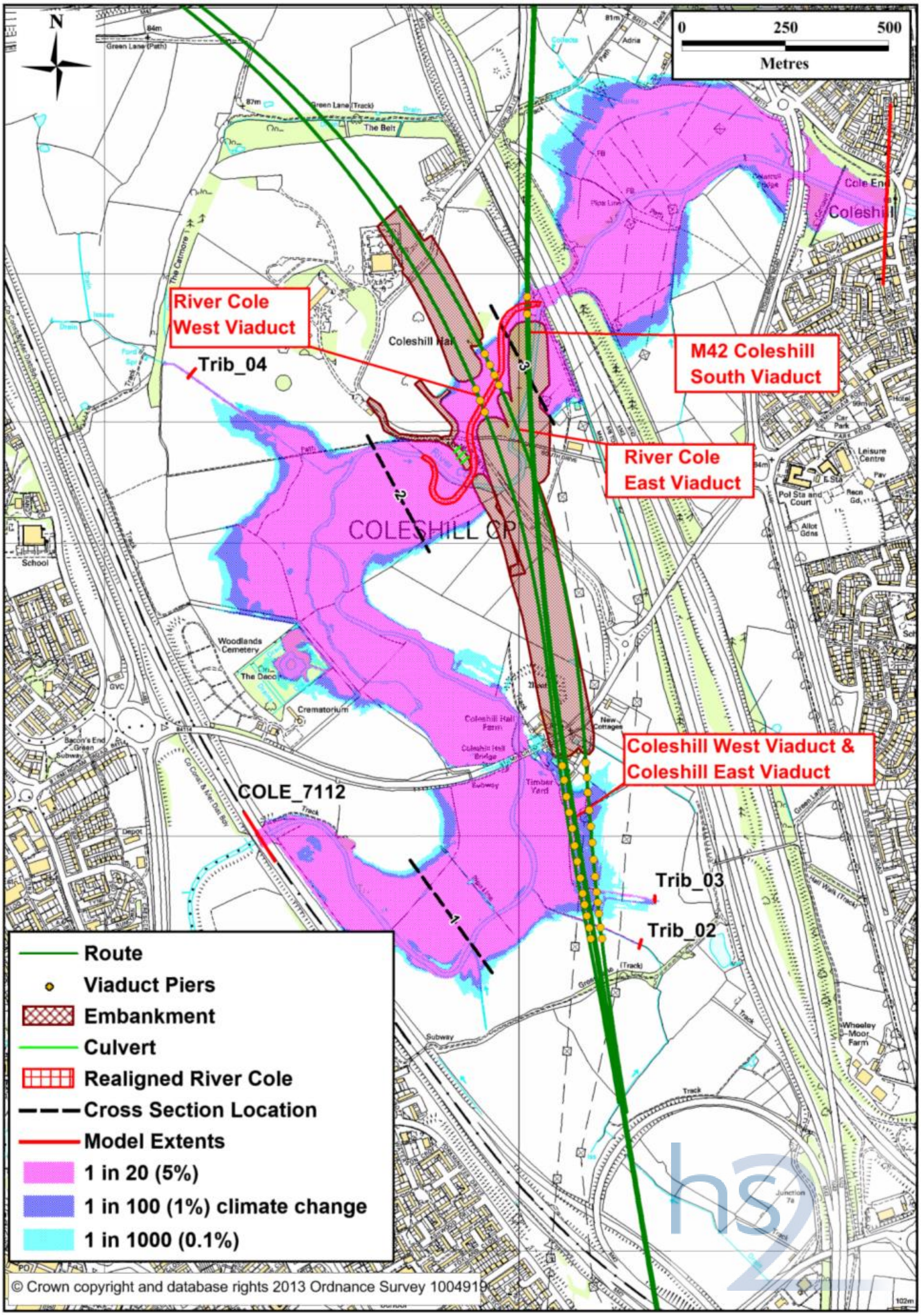


Figure 3: Crossing schematic and scheme flood extents



Hydrology

2.3.3 There was existing hydrology available for the watercourses and hence no additional hydrological assessment was undertaken as a part of this assessment. Therefore the flows for the River Cole and its tributaries were taken from the Environment Agency Flood Risk Mapping Study[7] as mentioned in Section 2.1.3 of this report. The hydrological assessment used the FEH statistical method to estimate the design peak flows. As a part of the Environment Agency study, the flow data from the river gauge at Coleshill was analysed and was deemed to be of insufficient quality to be used in that study. However, there are local analogue sites which were found to be suitable for use. Any uncertainty in the design inflows has been accounted for in the sensitivity assessment on modelled flows in this study.

2.3.4 A two dimensional model was constructed for the River Cole for the assessment of the Proposed Scheme which included inflow boundaries (refer to 'Hydraulics' section for details). The upstream inflow into the River Cole in the modelled reach was taken from the ISIS model node 'COLE_7112' of the Environment Agency. There are three tributaries flowing into the modelled reach of River Cole which were also added as inflow boundaries. The flows for these inflow boundaries are provided in Table 3.

Table 3: Hydrology: Modelled inflows for the River Cole model

Watercourse inflow boundary	Environment Agency Flood Zone	1 in 20 (5%) flow	1 in 100 (1%) climate change flow	1 in 1000 (0.1%) flow	Modelled structure
'Trib_02'	3	$0.09m^3/s$	$0.15m^3/s$	$0.20m^3/s$	Viaduct
'Trib_03'	3	$0.28m^3/s$	$0.46m^3/s$	$0.62m^3/s$	Viaduct
Trib_04	3	$1.70m^3/s$	$2.64m^3/s$	$3.10m^3/s$	Viaduct
'COLE_7112'	3	$63.3m^3/s$	$93.6m^3/s$	$114.1m^3/s$	Viaduct

Hydraulics

Environment Agency model

2.3.5 A one dimensional ISIS hydraulic model was originally created under commission from the Environment Agency for the purpose of generating a flood map under the Strategic Flood Risk Management (SFRM) Framework. This model covers a 21.5km length of the River Cole from Cole Ford near Sparkhill to the River Blythe confluence, which contains the section of the River Cole that is crossed by the route. The reach of interest for the proposed scheme was from the M6 road bridge to the M42 road bridge. Within this reach, the two tributaries crossed by Coleshill West Viaduct and Coleshill East Viaduct (SWC-CFA19-010 and SWC-CFA19-019) were not explicitly modelled but were included as inflow boundaries to the River Cole. This hydraulic model was modified as a part of the Proposed Scheme as discussed here.

Baseline model development

2.3.6 Following the review, the Environment Agency model was upgraded in various stages, utilising new topographic data and improving the watercourse-floodplain hydraulic mechanisms.

2.3.7 A more recent LiDAR dataset than that used in the original one dimensional ISIS model was available at the time of this assessment in 2012. The floodplain topography

within the original one dimensional ISIS model was lower than the new LiDAR data by up to 0.5m. Therefore, it was considered necessary to update the model with the new LiDAR dataset. The model was updated for the reach from 117m upstream of the Moorend Avenue Road Bridge (ISIS model node – 'COLE_8220') up to Lichfield Road Bridge (ISIS model node – 'COLE_2845'). The updated model showed up to 0.5m increase in peak levels for the 1 in 100 (1%) annual probability event and decreases of up to 0.3m near the route. This was attributed to the difference between the topography of the new LiDAR data and that used originally in the Environment Agency one dimensional ISIS model. The updated model was not recalibrated as the original Environment Agency model was not calibrated due to the unsuitability of the Coleshill river gauge. Therefore, the flows from the original model were used in this updated model. The resulting one dimensional model was suitable for representing the baseline scenario and initial scheme scenarios. However, as the scheme design became more complex due to the inclusion of a channel diversion) the one dimensional model was inadequate in simulating the change in floodplain conveyance, velocities and storage. Therefore, the decision was made to model the complex floodplain hydraulics as a two dimensional component.

2.3.8 In order to improve the floodplain hydraulics as a part of this modelling assessment, the one dimensional ISIS model of the River Cole was replaced with a two dimensional TUFLOW model. The TUFLOW model was built on a 2m grid resolution which was considered to be adequate in defining the channel topography of the River Cole. The two dimensional domain covered the floodplain and watercourse, the upstream extent of which began just downstream of the M6 and with the downstream extent at the Lichfield Road Bridge at Coleshill. The extents of the domain were defined by available LiDAR of 1m resolution. The Manning's roughness adopted was 0.04 for the channels and 0.05 for the floodplains.

2.3.9 The inflows to the River Cole and three tributaries were applied using a TUFLOW boundary condition polyline layer. These polyline layers were linked to a flow time hydrograph within a boundary condition database. These inflow boundaries were taken from the updated one dimension ISIS model and are referred by the relevant model node as shown in the 'Input data' table. A flow-head (HQ) polyline layer was applied at the downstream boundary of the River Cole, the slope of which was derived from the floodplain topography at that location (0.001). The flow routes of the three tributaries were represented as Z-lines which were GIS polylines extracted bed elevations from the DTM. Existing bridges on the River Cole were included in the model as two dimensional layered flow constriction shape layers, the dimensions of which were obtained from the one dimensional ISIS model. A percentage blockage was included which represented the percentage of the flow route blocked by bridge piers (if applicable).

2.3.10 The two dimensional model produced peak water levels which were 50-150mm lower than the updated one dimensional ISIS model in the study area between the M6 road bridge and the M42 road bridge. This was within the model tolerance limits and so the two dimensional model was considered adequate in simulating flooding within this area. East of the M42 road bridge, there were uncertainties in model outputs due to the downstream boundary. However, sensitivity runs were undertaken for the downstream boundary which showed these uncertainties having no significant impact

on peak levels between the M6 road bridge and the M42 road bridge. The bridge structures (especially M6 and M42) have been represented based on data from the one dimensional ISIS model. Therefore, the two dimensional model, utilising new LiDAR data, improved the simulation of complex floodplain hydraulics compared to that of the original Environment Agency model.

Scheme model

2.3.11 In the scheme model, the viaduct embankments were modelled as Z-shape layers, with arbitrarily high elevations. Viaduct piers were modelled as flow constriction shape layers, and were assigned a 50% blockage and a form loss coefficient in the attributes. The form loss coefficient accounted for the form loss relating to the shape of the piers. A Z-shape layer was added to represent the Manor Road diversion which also included three flood relief culverts which were represented by one dimensional network layers. The elevations of the Manor Road diversion was above the peak levels of the 1 in 100 (1%) annual probability with an allowance for climate change event.

2.3.12 The scheme model also included a channel diversion just upstream of the M42/M6 TOLL motorway. This diversion was modelled using a z shape layer, with the upstream and downstream inverts being defined from the River Cole channel bed at these respective locations of the diversion, and the channel bed in between these being interpolated from the inputted upstream and downstream invert levels. A section of the existing channel was removed, again using a Z-shape layer, the levels of which were defined from the adjacent floodplain from the now redundant section of the River Cole. Around the new meander bends of the channel diversion, sections of the surrounding topography were reduced to represent a realistic floodplain level adjacent to the diverted section of the River Cole. This was achieved using Z-shape layers. Two existing bridges, the redundant Manor Road and South Drive Bridge crossings, were removed due to the River Cole channel diversion.

2.3.13 If the scheme model showed significant increase in peak levels, the scheme scenario was run with a mitigation measure for the 1 in 100 (1%) annual probability with an allowance for climate change event. An area for replacement flood storage area was provided in the scheme design. The flood storage areas were represented by a Z-shape layer set to lower topographic levels which provided the required storage volumes. To provide the effective flood storage, the ground levels needed to be set at levels to ensure that the flood storage was not fully utilised before the peak of the flood event.

2.3.14 The resulting baseline and scheme models were run at a one second timestep for a duration of 22 hours. TUFLOW 2012 was the software version used for this assessment.

Hydraulic constraints

2.3.15 The main hydraulic constraints in this area are the Birmingham Road Bridge, M42 Bridge, M6 Bridge and the Lichfield Road Bridge. All these structures have been represented in the model, utilising the survey data from the original Environment Agency one dimensional ISIS model.

Model outputs

2.3.16 The baseline floodplain widths for the 1 in 100 (1%) annual probability with an allowance for climate change event were extracted at the various viaduct crossings. At Coleshill West and East viaduct, the floodplain width was 291m; at River Cole West and East viaduct was 310m; and at M42 Coleshill South viaduct was 334m.

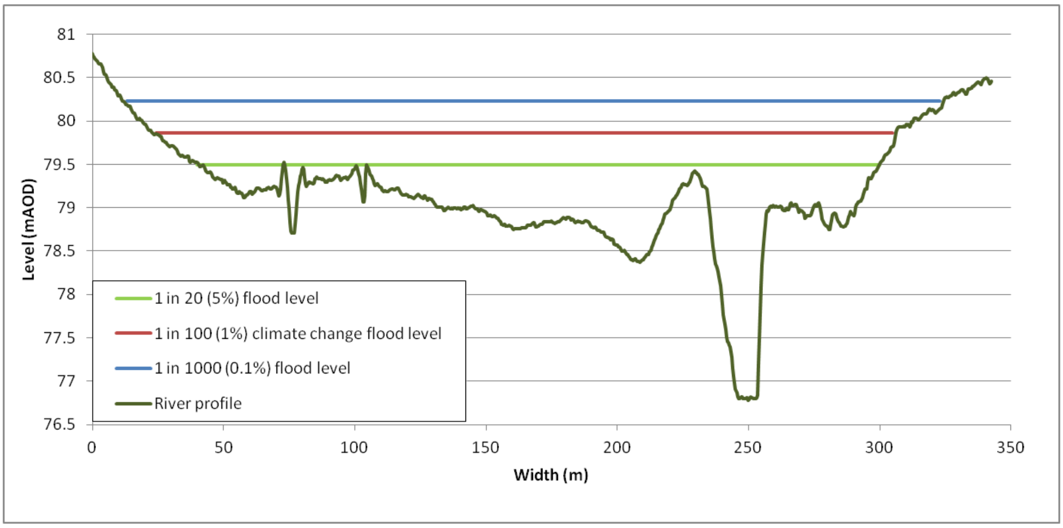
2.3.17 The watercourse cross section along with the modelled baseline peak levels were extracted at three locations as shown in Figure 2. These cross sections with flood levels are provided in Figure 4.

2.3.18 The modelled baseline and scheme peak levels were extracted at the some key locations as shown in Figure 5. The peak levels along with impacts of the Proposed Scheme are summarised in Table 4. Additional results are provided for the Proposed Scheme along with mitigation measures, for which the model was run for the 1 in 100 (1%) annual probability with an allowance for climate change event.

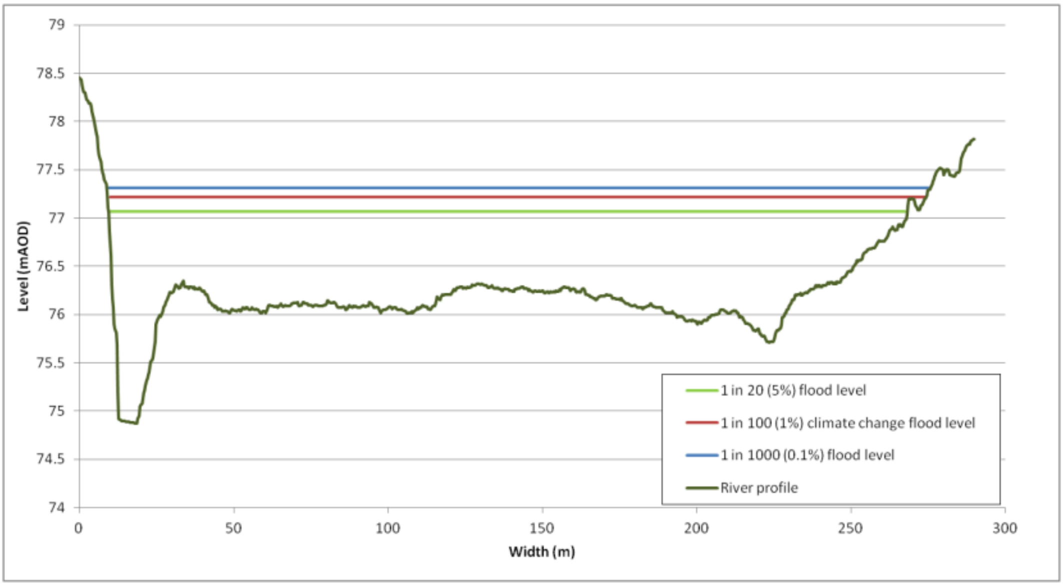
2.3.19 The peak velocity contours for the baseline and scheme scenario for the 1 in 100 (1%) annual probability with an allowance for climate change event are provided in Figure 6 and Figure 7 respectively.

Figure 4: Cross sections and flood levels for the River Cole

Section 1



Section 2



Section 3

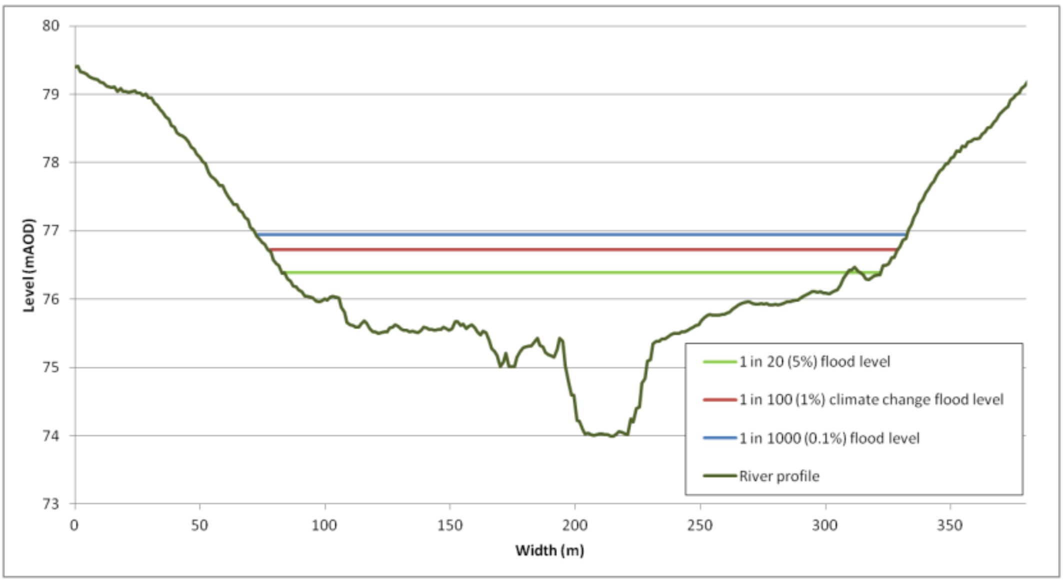


Figure 5: Key locations of peak water levels

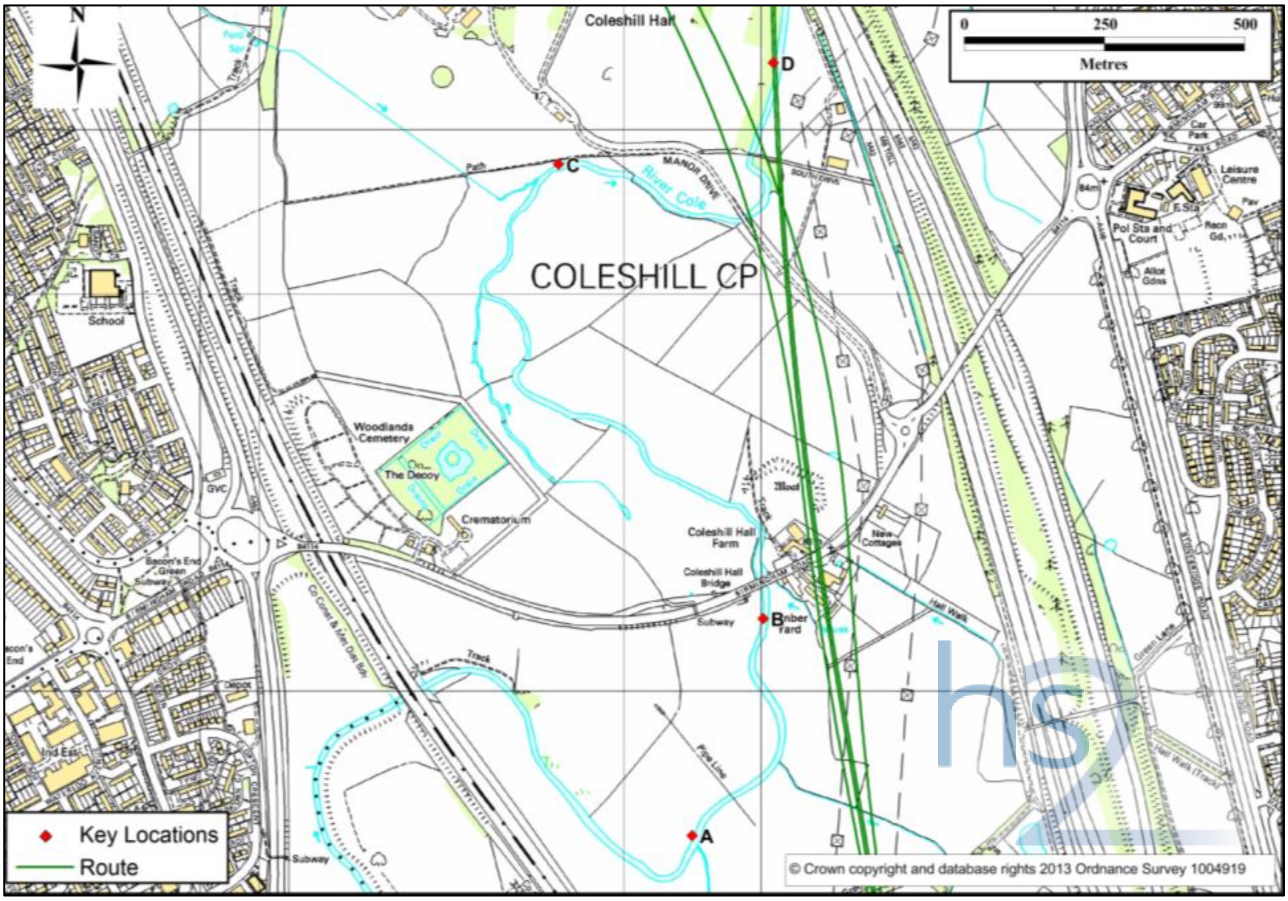


Table 4: Modelled peak levels for the River Cole

Flood event	Location	Peak flood level			Change in flood level with scheme	Change in flood level with scheme plus mitigation
		Baseline	Scheme	Scheme with mitigation*		
1 in 20 (5%)	A	79.498mAOD	79.498mAOD	-	0mm	-
	B	79.220mAOD	79.220mAOD	-	0mm	-
	C	77.068mAOD	77.171mAOD	-	103mm	-
	D	76.395mAOD	76.607mAOD	-	212mm	-
1 in 100 (1%) climate change	A	79.863mAOD	79.863mAOD	76.863mAOD	0mm	0mm
	B	79.784mAOD	79.784mAOD	79.784mAOD	0mm	0mm
	C	77.219mAOD	77.568mAOD	77.259mAOD	349mm	40mm
	D	76.724mAOD	76.950mAOD	76.640mAOD	226mm	-84mm
1 in 1000 (0.1%)	A	80.226mAOD	80.233mAOD	-	7mm	-
	B	80.190mAOD	80.199mAOD	-	9mm	-
	C	77.313mAOD	77.833mAOD	-	520mm	-
	D	76.944mAOD	77.160mAOD	-	216mm	-

Figure 6: Baseline peak velocity contours for 1 in 100 (1%) climate change of River Cole

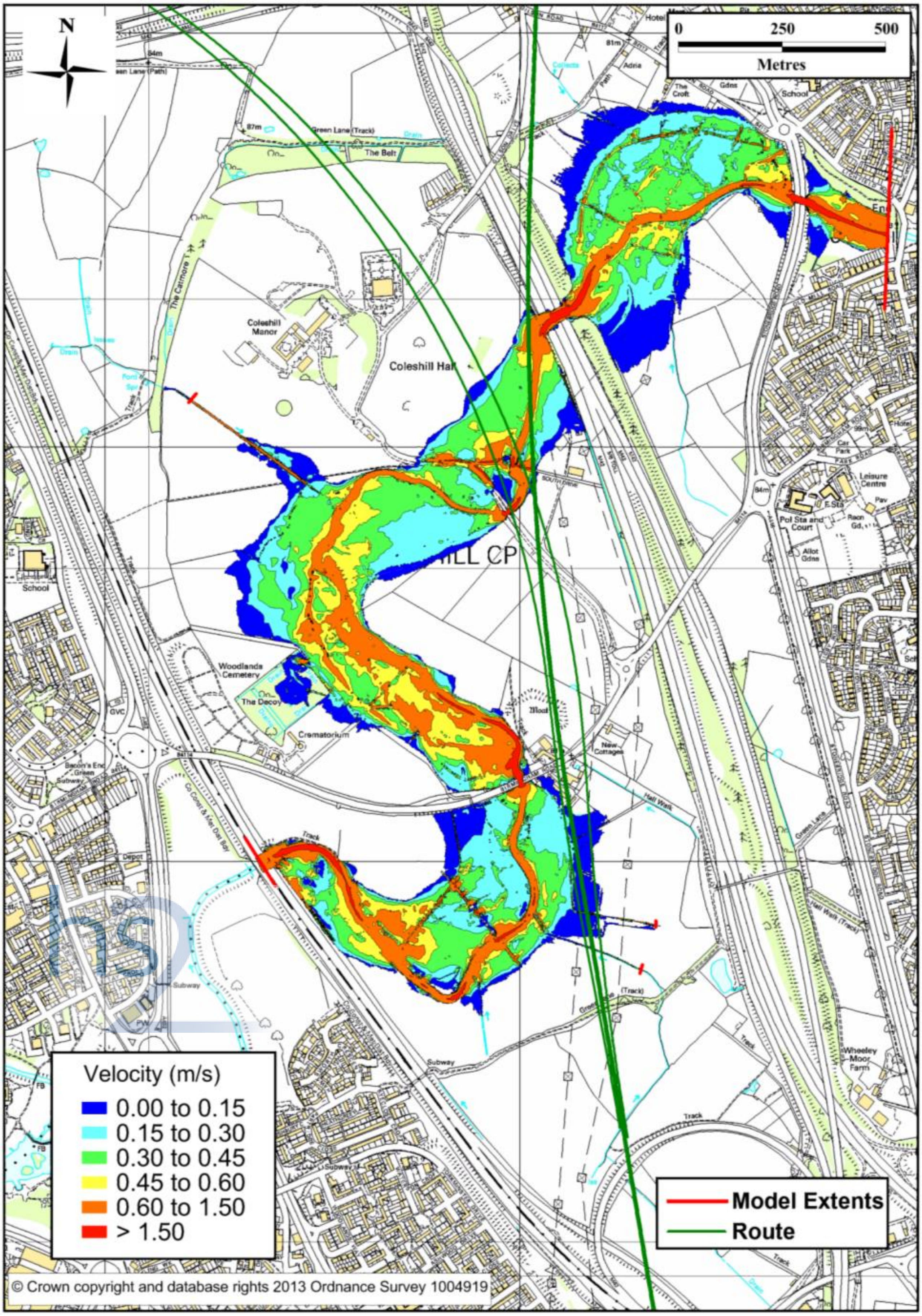
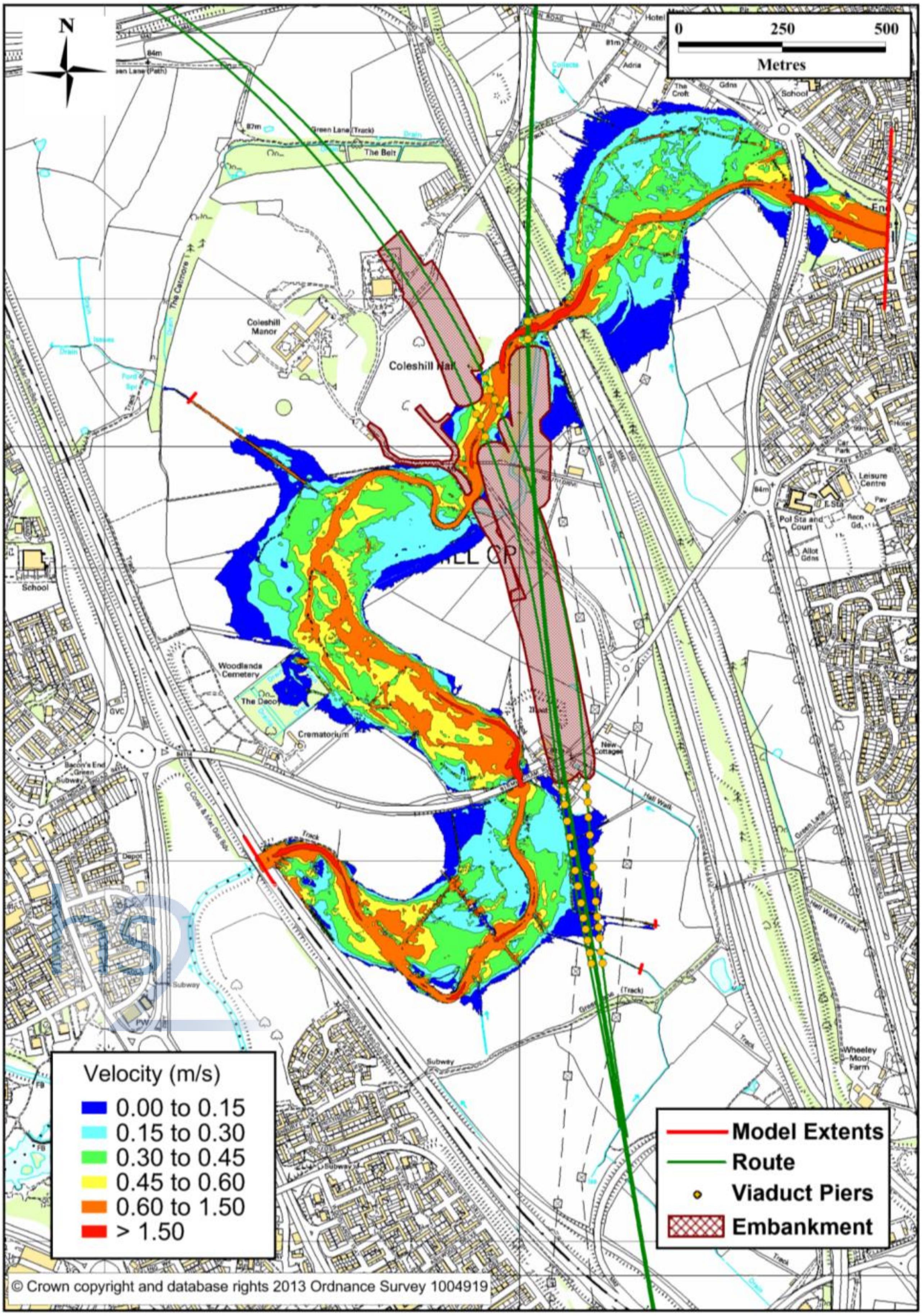


Figure 7: Scheme peak velocity contours for 1 in 100 (1%) climate change event of River Cole



Sensitivity assessment

2.3.20 Sensitivity assessment was carried out on inflows for the 1 in 100 (1%) annual probability with an allowance for climate change event on the baseline model and scheme model. A 20% increase of flows causes up to a 305mm increase in peak levels. The peak levels with the sensitivity allowance are still well below the soffit level, providing the necessary clearance of 600mm.

2.3.21 This increase in peak levels showed an increase in flooded extent but did not affect any additional receptors apart from agricultural land. Therefore, the impact of the scheme on flood risk will still be valid with these sensitivity changes.

Conclusions

2.3.22 The impact of the Proposed Scheme on peak levels and velocities for the 1 in 100 (1%) annual probability with an allowance for climate change event are summarised in this section

2.3.23 For Coleshill West Viaduct and Coleshill East viaduct, there was no increase in peak levels with minimal changes in velocities. Therefore, the viaduct structure at this location has no impact on flood risk.

2.3.24 For River Cole West viaduct and Coleshill East viaduct, without mitigation there was increase in peak levels of up to 349mm for the 1 in 100 (1%) annual probability with an allowance for climate change event which is categorised as major impact on flood risk. The reach with increases in peak levels of greater than 10mm was limited to 1,117m upstream of the crossing. There is a shift in velocity patterns due to the realignment of the River Cole as shown in the figure. There are localised increases in velocities of up to 0.13m/s at the viaduct structure and minimal changes elsewhere.

2.3.25 For M42 Coleshill South viaduct, without mitigation there were increases in peak levels of up to 226mm for the 1 in 100 (1%) annual probability with an allowance for climate change event which is categorised as major impact on flood risk. The increase in peak levels of greater than 10mm extends 1,835m upstream of this viaduct crossing. It should noted that the impacted reach upstream reflects the combined effect of the upstream viaducts as well. There is a shift in velocity patterns due to the realignment of the River Cole as shown in the figure. There are localised increases in velocities of up to 1.82m/s at the viaduct structure and minimal changes elsewhere.

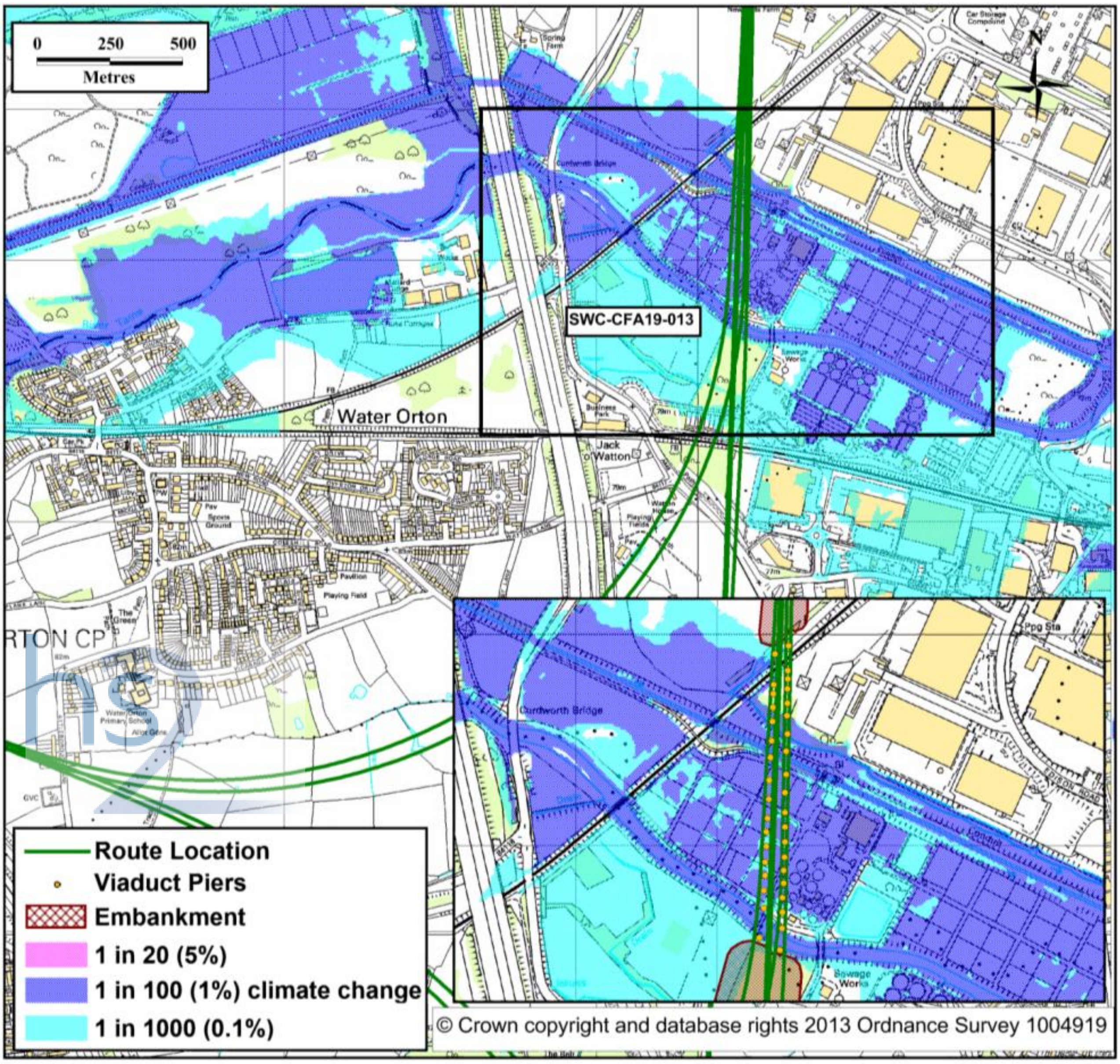
2.3.26 For the crossings River Cole West viaduct, Coleshill East viaduct and M42 Coleshill South viaduct, replacement floodplain storage areas were identified upstream of Manor Drive and at the location between Coleshill west viaduct and River Cole east viaduct. Hydraulic modelling has shown to reduce the major impact on flood level to a minor impact. The area along this reach of the River Cole is surrounded by less vulnerable land uses and hence no vulnerable development will be at risk if the Proposed Scheme does result in a minor increase in flood level.

2.4 River Tame viaducts

2.4.1 This crossing consists of the River Tame viaduct structures (River Tame west viaduct, River Tame east viaduct and Water Orton No.2 viaduct) which will cross the River Tame, SWC-CFA19-013 (WR-05-055, A5, Volume 5, CFA19, Map Book), as shown in

Figure 8. The watercourse flows from west of the crossing and continues east as shown in Figure 8.

Figure 8: Crossing location and flood extents for the River Tame West viaduct



Hydrology

2.4.2 The hydrology of the River Tame was taken from the Environment Agency Flood Risk Mapping Study[8]. The hydrological assessment undertaken as a part of the Flood Risk Mapping Study[8] and used standard FEH methods: the Statistical method and the Flood Studies Report Rainfall-Runoff method. The Statistical method was used to estimate the peak design flows and the Rainfall-Runoff method to generate hydrographs scaled to these peak flow estimates. For the final flood frequency curves, single site analysis was adopted for lower design events, and pooled analysis for higher design events. The hydrology was calibrated by comparing the modelled and observed ratings at various gauges. The flow at the crossing is provided in Table 5.

Table 5: Modelled inflows for the River Tame West viaduct

Watercourse identifier	Environment Agency Flood Zone	1 in 100 (1%) climate change flow	1 in 1000 (0.1%) flow	Modelled structure
SWC-CFA19-013	3	210.74m^3/s	312.67m^3/s	Viaduct

Hydraulics

2.4.3 The hydraulic model available at the time of this assessment was from the Environment Agency Flood Risk Mapping Study[8] undertaken in 2009. There were two hydraulic models covering the Upper Tame and Lower Tame which were built using ISIS version 3.0. There was an additional two dimensional model using ISIS-TUFLOW at Bescot Junction and Brookvale Road, Witton, which gave a better understanding of the complex flow regime at this location. However, the two dimensional model extent does not cover the reach of the River Tame near the crossing. Therefore, the Lower Tame one dimensional ISIS model was used for the purposes of this assessment as this covered the study area. The one dimensional model was adequate in defining the floodplain hydraulics at this location. The two tributaries that have their confluence with the River Tame at Curdworth Viaduct were not modelled explicitly but were included as inflow points to the Lower Tame model as a part of this assessment.

2.4.4 The Lower Tame ISIS model was amended at the proposed crossing to improve the floodplain hydraulics and includes the two tributaries at Curdworth Viaduct as point inflows. The extended cross sections near the proposed crossing were replaced by channel sections with ISIS reservoir units representing the floodplain areas. There were two floodplain areas located upstream and downstream of the crossing and linked together by an ISIS floodplain section. The Level-Area relationship of the floodplain areas and topography of the floodplain section were extracted from the available LiDAR DTM.

2.4.5 The proposed viaduct structure was modelled by modifying the floodplain section data to include pier widths and embankment sections. The soffit levels were not added into the model. This was because the 1 in 1000 (0.1%) annual probability modelled peak flood levels, along with sufficient clearance, would form the basis of designing the soffit heights.

2.4.6 The main hydraulic constraint is the railway bridge 300m upstream of the viaduct crossing which has been represented in the Environment Agency ISIS model.

2.4.7 The baseline floodplain width at the crossing for a 1 in 100 (1%) annual probability with an allowance for climate change event was 494m. The cross section with modelled peak level is provided in Figure 9. The modelled peak levels and the impact of the scheme are summarised in Table 6.

Figure 9: Cross section with flood levels for River Tame

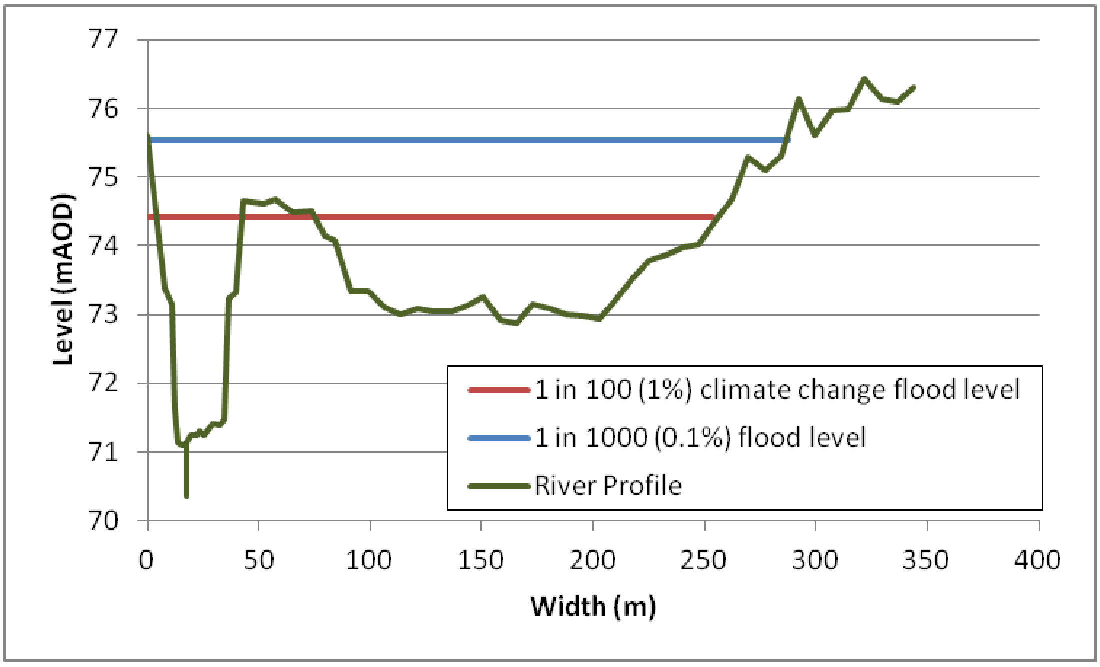


Table 6: Modelled peak levels for the River Tame viaducts

Flood event	Peak flood level		Change in flood level
	Baseline	Scheme	
1 in 100 (1%) climate change	74.415mAOD	74.415mAOD	0mm
1 in 1000 (0.1%)	75.543mAOD	75.543mAOD	0mm

Sensitivity assessment

2.4.8 Sensitivity assessment was carried out on inflows for the 1 in 100 (1%) annual probability as a part of the Environment Agency Flood Risk Mapping Study[8]. A 20% increase in inflows caused up to a 272mm increase in peak levels. However, the soffit level will be sufficiently above the modelled peak levels with sensitivity allowance, providing the design clearance of 600mm. Therefore, the sensitivity changes on peak levels will not affect the vertical alignment of the route.

Conclusions

2.4.9 The Proposed Scheme showed no increase in peak levels for the 1 in 100 (1%) annual probability with an allowance for climate change event. Therefore, the viaduct structure at this location has no impact on flood risk.

3 FEH proformas

3.1 Overview

3.1.1 This section provides the FEH Proformas for the hydrological calculations of the various watercourses for which there were no existing hydrology available.

3.1.2 The FEH Proformas are based on the Environment Agency supporting document to the flood estimation guidelines[4].

3.1.3 The watercourse crossings in this study area covered in the FEH Proforma are Coleshill culvert (SWC-CFA19-010) and Water Orton culvert (SWC-CFA19-019).

3.1.4 For Coleshill West viaduct, Coleshill East viaduct, River Cole West viaduct, River Cole East viaduct and M42 Coleshill South viaduct; the hydrology for the River Cole and its tributaries has been taken from the Environment Agency Flood Risk Mapping Study[7]. The FEH proforma for the hydrological assessment are provided as part of this Flood Risk Mapping Study[7] and hence not reproduced here.

3.1.5 For the River Tame viaducts, the hydrology for the River Tame was taken from the Environment Agency Flood Risk Mapping Study[8]. The FEH proforma for the hydrological assessment is provided as part of this Flood Risk Mapping Study[8] and hence not reproduced here.

3.2 Method statement

Overview of requirements for flood estimates

Item	Comments
Give an overview which includes: Purpose of study Approx no. of flood estimates required Peak flows or hydrographs Range of return periods and locations Approx time available	This proforma outlines the hydrological calculations carried out for the assessment of flood risk. As part of the Proposed Scheme, these watercourses will require culvert structures under the route and hence it must be ensured that the culvert would be of sufficient capacity. It is vital that the proposed structures are not under designed and hence conservative flows are necessary in line with current requirements of the Proposed Scheme. At a later stage, if a more in-depth assessment determines lower flow, and hence smaller structures would have sufficient capacity, this is acceptable. Flows are required at all watercourse crossings within the study area. The Tame catchment located in this section of the route contains 29 crossings. This particular assessment outlines the derivation of flows at two of these locations within this study area for the 1 in 20 (5%) annual probability, 1 in 100 (1%) annual probability, 1 in 100 (1%) annual probability with an allowance for climate change and the 1 in 1000 (0.1%) annual probability.

Overview of catchment

Item	Comments
Brief description of catchment, or reference to section in accompanying report.	The two catchments assessed here range in size from $0.23km^2$ to over $0.26km^2$

Source of flood peak data

Item	Comments
Was the HiFlows UK dataset used? If so, which version? If not, why not? Record any changes made	No. Only method implemented at this stage was the scaling factor method as the catchments were not represented on the FEH CD-ROM. Therefore, HiFlows data is not utilised.

Gauging stations (flow or level)

3.2.1 Gauging stations at the sites of flood estimates or nearby at potential donor sites.

3.2.2 Local donor sites have been sought however in most cases the catchment area of the subject catchment was found to be significantly smaller than that of any potential local donor.

Watercourse	Station name	Gauging authority number	National River Flow Archive number (used in FEH)	Grid reference	Catchment area (km²)	Type (rated/ ultrasonic/ level	Start and end of flow record
Not applicable							

Data available at each flow gauging station

Station name	Start and end of data in HiFlows UK	Update for this study?	Suitable for QMED	Suitable for pooling?	Data quality check needed?	Other comments on station and flow data quality – e.g. information from HiFlows-UK, trends in flood peaks, outliers
Not applicable						
Give link/reference to any further data quality checks carried out						

Rating equations

Station name	Type of rating e.g. theoretical, empirical; degree of extrapolation	Rating review needed	Reasons – e.g. availability of recent flow gaugings, amount of scatter in the rating.
Not applicable			
Give link/reference to any rating reviews carried out			

Other data available and how it has been obtained

Type of data	Data relevant to this study	Data available?	Source of data and licence reference if from EA	Date obtained	Details
Check flow gaugings (if planned to review ratings)	No				
Historic flood data – give link to historic review if carried out.	No				

Type of data	Data relevant to this study	Data available?	Source of data and licence reference if from EA	Date obtained	Details
Flow data for events	No				
Rainfall data for events	No				
Potential evaporation data	No				
Results from previous studies	Scaling factors from overall ReFH assessment of the catchments of this section of the Proposed Scheme.				
Other data or information (e.g. groundwater, tides)	No				

Initial Choice of approach

Is FEH appropriate? (it may not be for very small, heavily urbanised or complex catchments) If not, describe other methods to be used.	These catchments were not represented on the FEH CD-ROM and hence a scaling method based on area has been utilised.
Outline the conceptual model, addressing questions such as: **Where are the main sites of interest?** **What is likely to cause flooding at those locations? (peak flows, flood volumes, combinations of peaks, groundwater, snowmelt, tides…)** **Might those locations flood from runoff generated on part of the catchment only, e.g. downstream of a reservoir?** **Is there a need to consider temporary debris dams that could collapse?**	The main sites of interest are at the crossing locations and hence are the points at which flow has been derived. Each point at which flow has been derived has been named in accordance with the associated watercourse identifier at the crossings. At this stage it is considered that peak flows are likely to be the main cause of flooding, following development, due to the potentially constricting culvert or bridge. As part of this assessment it is not deemed necessary to consider the risk of a temporary dam collapse.
Any unusual catchment features to take into account? **e.g.** **highly permeable – avoid ReFH if BFIHOST>0.65, consider permeable catchment adjustment for statistical method if SPRHOST<20%** **highly urbanised – avoid standard ReFH if URBEXT1990>0.125; consider FEH Statistical or other alternatives; consider method that can account for differing sewer and topographic catchments** **pumped watercourse – consider lowland catchment version of rainfall-runoff method** **major reservoir influence (FARL<0.90) – consider flood routing** **extensive floodplain storage – consider choice of method carefully**	None

Initial choice of method(s) and reasons **Will the catchment be split into subcatchments? If so, how?**	The catchments at Coleshill culvert and Water Orton culvert were not defined in FEH CD-ROM and hence a scaling factor based on area has been utilised to estimate flow at these locations. A ReFH assessment of the other catchments within this section of the Proposed Scheme was undertaken which provided a range of scaling factors. A conservative scaling factor was adopted for each of the catchments at these crossings of Coleshill culvert and Water Orton culvert.
Software to be used (with version numbers)	FEH CD-ROM v3.0[10] ISIS Free 3.3

3.2.3 The table below lists the locations of subject sites. The site codes listed below are used in all subsequent tables to save space.

Summary of subject sites

Site Code	Watercourse	Site	Easting	Northing	Area on FEH CD-ROM (km^2)	Revised catchment area if altered
SWC-CFA19-010	Ordinary watercourse (River Cole tributary)	Route crossing at structure shown in the site code column.	418,480	289,730	Not on FEH CD-ROM	0.23km^2
SWC-CFA19-019	Ordinary watercourse (River Tame tributary)	Route crossing at structure shown in the site code column.	418,460	290,570	Not on FEH CD-ROM	0.26km^2
Reasons for choosing above locations		Locations the Proposed Scheme will cross the respective watercourses.				

Checking catchment descriptors

Record how catchment boundary was checked and describe any changes (refer to maps if needed)	Catchments were not represented on the FEH CD-ROM and were determined using OS and topographic mapping.
Record how other catchment descriptors (especially soils) were checked and describe any changes. Include before/after table if necessary.	Not applicable
Source of URBEXT	Not applicable
Method for updating of URBEXT	Not applicable

3.3 Scaling for catchment not represented on the FEH CD-ROM

Site code	Manual catchment area	Scaling factor 1 in 20 (5%) flow per km^2	Scaling factor 1 in 100 (1%) flow per km^2	Scaling factor 1 in 1000 (0.1%) flow per km^2	Scaled flows 1 in 20 (5%)	Scaled flows 1 in 100 (1%) climate change	Scaled flows 1 in 1000 (0.1%)
SWC-CFA19-010	0.23km^2	1.00	1.51	2.87	0.23	0.42	0.79

[10] *FEH CD-ROM v3.0* © NERC (CEH). © Crown copyright. © AA. 2009. All rights reserved.

Site code	Manual catchment area	Scaling factor 1 in 20 (5%) flow per km²	Scaling factor 1 in 100 (1%) flow per km²	Scaling factor 1 in 1000 (0.1%) flow per km²	Scaled flows 1 in 20 (5%)	Scaled flows 1 in 100 (1%) climate change	Scaled flows 1 in 1000 (0.1%)
SWC-CFA19-019	0.26km²	1.00	1.51	2.87	0.26	0.47	0.90
The flows in this table were estimated using the largest scaling factor as determined in the 'Flood estimates from the ReFH method' table and a 10% allowance for data error. This ensures that the values flows estimated for these catchments not represented on the FEH CD-ROM are conservative.							

3.4 Discussion and summary of results

Comparison of results from different methods

3.4.1 This table compares peak flows from various methods with those from the FEH Statistical method at example sites for two key design events. Blank cells indicate that results for a particular site were not calculated using that method.

Site Code	Ratio of peak flow to FEH Statistical peak					
	1 in 2 (50%)			1 in 100 (1%)		
	ReFH	Other method	Other method	ReFH	Other method	Other Method
	Not applicable			Not applicable		

Only the ReFH method was carried out as part of this assessment.

Final choice method

Choice of method and reasons – include reference to type of study, nature of catchment and type of data available.	The ReFH method was carried out for one catchment which was represented on the FEH CD-ROM. Flows for the three catchments not represented on the FEH CD-ROM were determined by using a scaling factor based on the estimated flows for the other (FEH CD-ROM represented) catchments. The scaling took the most conservative value and also included an allowance for data error.

Assumptions, limitations and uncertainty

List the main assumptions made (specific to this study)	The scaling factor is considered a conservative approach and hence produces conservative flow estimates for the catchment not represented on the FEH CD-ROM.
Discuss any particular limitations, e.g. applying methods outside the range of catchment types or return periods for which they were developed	None
Give what information you can on uncertainty in the results – e.g. confidence limits for the QMED estimates using FEH 3 12.5 or the factorial standard error from Science Report SC050050 (2008).	There is some uncertainty with the results based on the assumptions listed above, however it is considered that the results are conservative and hence would be over-estimating, rather than under-estimating flows.
Comment on the suitability of the results for future studies, e.g. at nearby locations or for different purposes.	The results have been completed for the purposes of the assessment of flood risk as the proposed crossings. The results should not be used for other studies with the exception for comparative purposes.
Give any other comments on the study, for example suggestions for additional work.	When the assessment moves to the detailed design phase it may be useful that the catchment boundaries are checked against LiDAR, OS mapping and other such sources. It is also recommended that the FEH Statistical method is carried out, particularly for high risk crossings. If possible the FEH Statistical method should be carried out for all catchments for comparative purposes and to provide a greater level of confidence with the results.

Checks

Are the results consistent, for example at confluences?	Not applicable
What do the results imply regarding the return periods of floods during the period of record?	Not applicable
What is the 100-year growth factor? Is this realistic? (The guidance suggests a typical range of 2.1 to 4.0)	Not determined.
If 1000-year flows have been derived, what is the range of ratios for 1000-year flow over 100-year flow?	Not applicable
What range of specific runoffs (l/s/ha) do the results equate to? Are there any inconsistencies?	Not applicable
How do the results compare with those of other studies? Explain any differences and conclude which results should be preferred.	None.
Are the results compatible with the longer-term flood history?	None.
Describe any other checks on the results	None.

Final results

Site code	**Flood peak for the following flood events**			
	1 in 20 (5%)	**1 in 100 (1%)**	**1 in 100 (1%) climate change**	**1 in 1000 (0.1%)**
SWC-CFA19-010	0.23m^3/s	0.35m^3/s	0.42m^3/s	0.79m^3/s
SWC-CFA19-019	0.26m^3/s	0.39m^3/s	0.47m^3/s	0.90m^3/s
If flood hydrographs are needed for the next stage of the study, where are they provided? (e.g. give filename of spreadsheet, name of ISIS model, or reference to table below)				Hydrographs were provided where necessary.